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A Two-Bladed configuration for the DTU 10 MW RWT: Loads Considerations

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Abstract

As the size of wind turbine rotors continuously grows, the need for innovative solutions that would yield to lighter rotor configurations becomes more urgent. Traditional wind turbine designs have favored the classic three-bladed upwind rotor configuration. This work presents instead a concept study on an alternative downwind two-bladed rotor configuration.

The study is based on the DTU 10-MW Reference Wind Turbine (RWT) model. The aerodynamic planform of the original rotor is maintained, and the rotor solidity is kept by increasing the blade chord by 50 %. The configuration allows saving 30 % of the rotor weight and material, but implies several drawbacks: lower power output due to increased tip losses effects, and increased load variations and hence fatigue damage.

To mitigate the load amplification caused by the interaction between the tower frequency and the rotational forcing, the tower mode frequency is lowered with a modified tower stiffness distribution. The loads caused by the aerodynamic unbalance are instead addressed by introducing a teetering hub configuration. The load alleviation potential of the teetering hub, and the required teeter angle range are evaluated for different stiffness values of the teeter bearing.

Objectives

- Propose a two bladed rotor design for the DTU 10 MW RWT
- The first design iteration is based on constant solidity scaling of the rotor geometry
- Quantify the power losses due to increased tip-loss effects
- Quantify the increase of the fatigue damage loads, and identify its sources
- Investigate aeroelastic interaction between tower frequency and the dominant 2P rotational forcing
- Investigate the load alleviation potential of a teetering hub configuration

Methods

➢ *2 Bladed Rotor Design:*

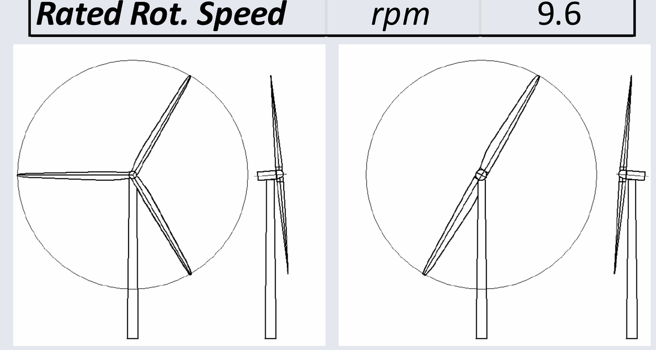
Constant solidity approach:

- Chord length and blade geometry scaled by 1.5.
- Blade structure approximated to a spar with rectangular cross section [2]
- Cross section thickness reduced by 1/1.5
- Same blade weight, blade stiffness increased by 1.5^2

With constant solidity design:

- Same aerodynamic design of the rotor
- Same Tip Speed Ratio, same control setup
- **Rotor mass reduced by 33 %**

DTU 10 MW RWT		
Rated Power	*MW*	10
Num. Blades		3
Rotor Diam.	*m*	178.3
Blade length	*m*	86.35
Hub height	*m*	119.0
Rated Wind Speed	*m/s*	11.4
Rated Rot. Speed	*rpm*	9.6



Mass [ton]	*3 Bladed*	*2 Bladed*
Blade	41.70	41.70
Rotor	125.10	83.40

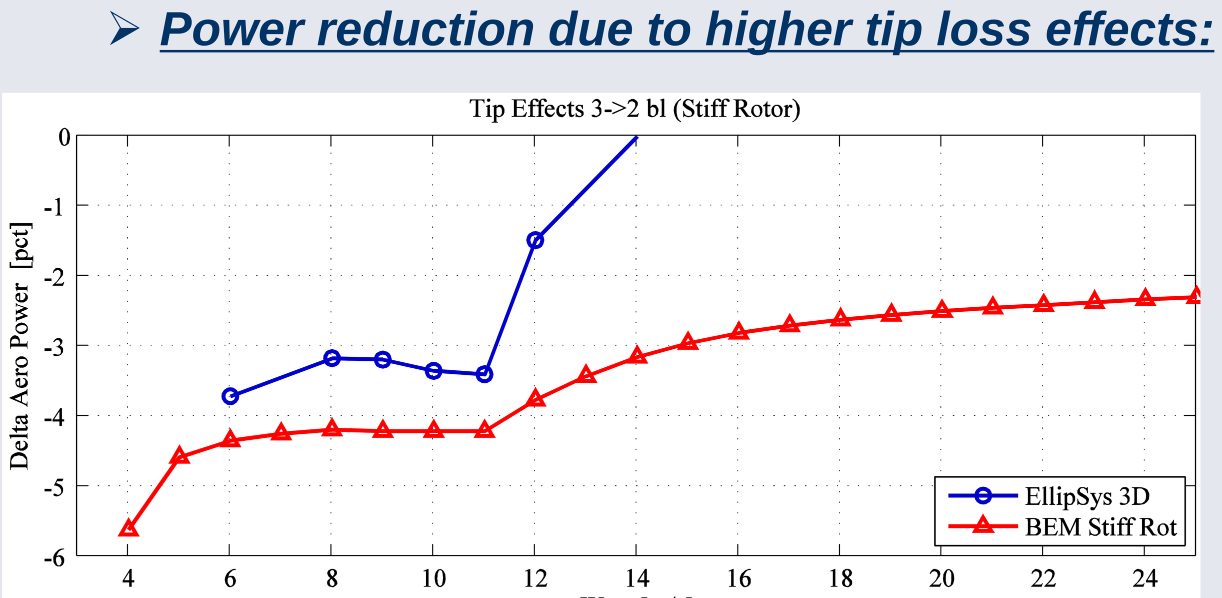
➢ *Simulation Setup:*

- DTU 10 MW Reference Wind Turbine (RWT) [6]
- Aeroelastic code HAWC2 [1] (BEM and multibody)
- Wind field conditions as IEC normal operation conditions [3]
- Mean wind speed at hub height of 10 m/s.
- Mann's 3D turbulent wind fields [4], TI 0.1834 (IEC class B).

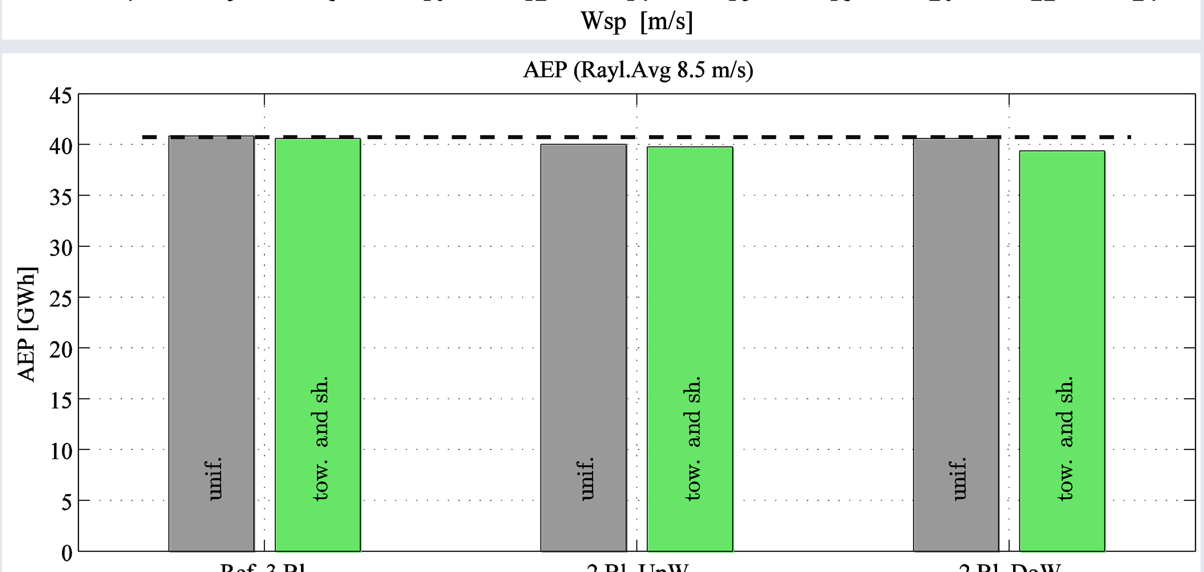
Results

The proposed rotor configuration reduces the weight of the rotor by one third, but has significant drawbacks: ***reduction of power output***, and ***load increase***.

➢ *Power reduction due to higher tip loss effects:*



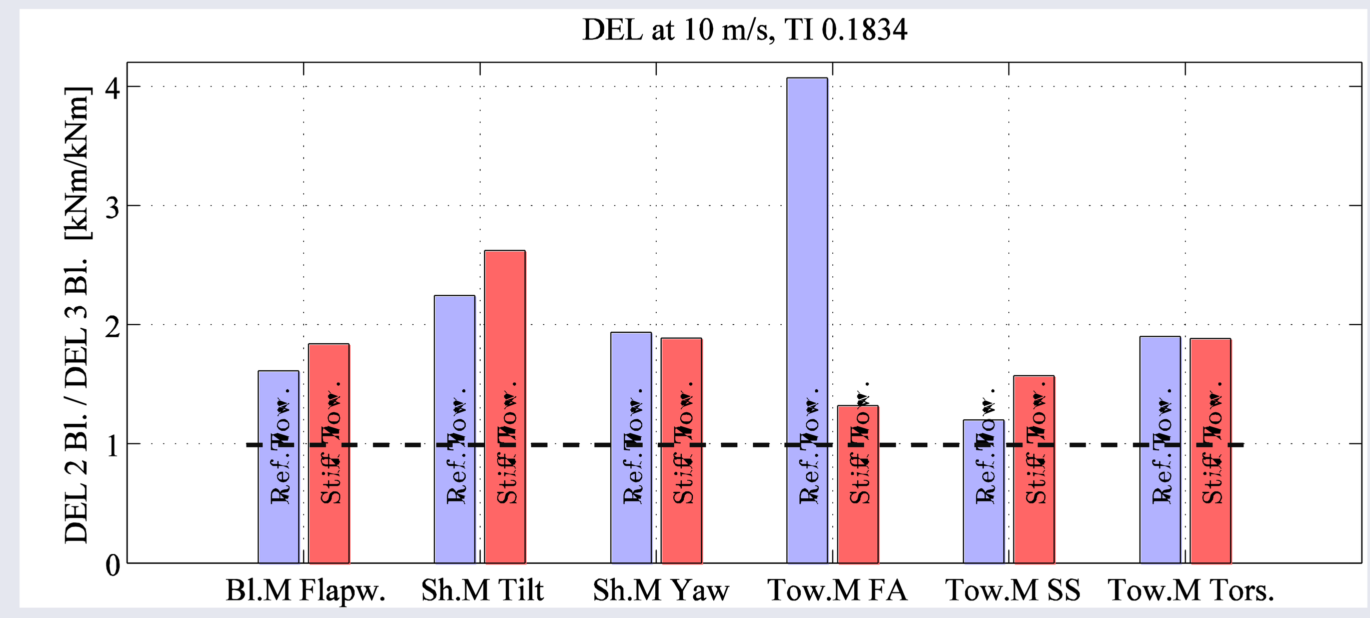
Due to increase tip losses effects, the Cp is reduced by 4.2% according to BEM, 3.5% in 3D CFD simulations performed with ElllipSys.



The tip losses yield to a 2% reduction of AEP.

A further 1% is lost due to increased tower shadow effects in the dowwind configuration.

➢ *Increase of fatigue Damage Equivalent Loads:*

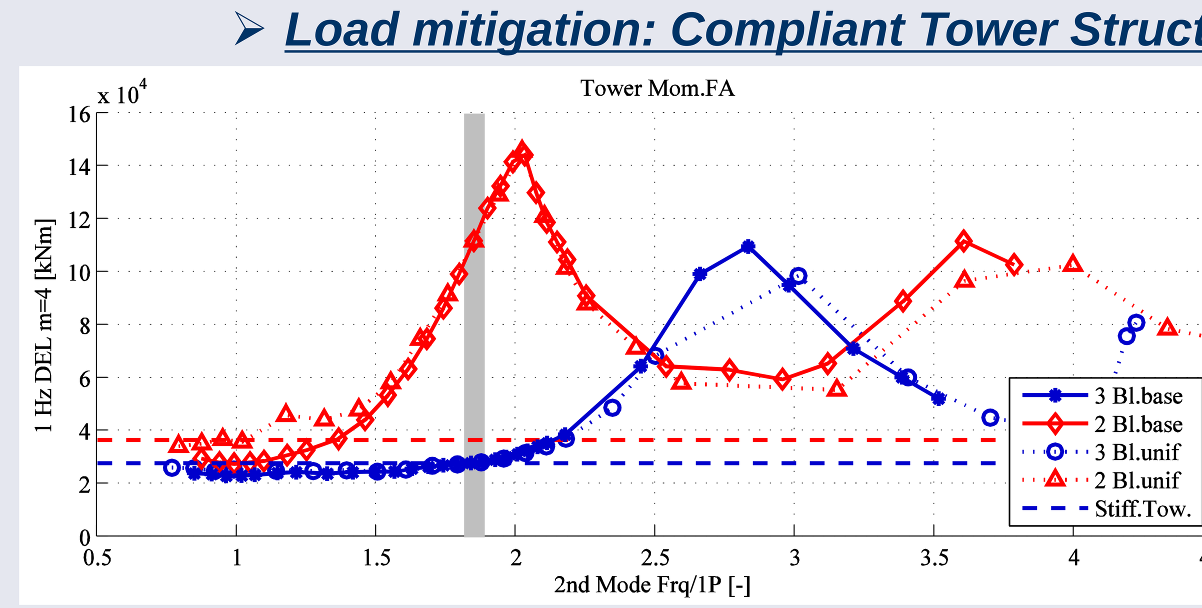


Longer chord increases DEL on blade (+50 %).

Aerodynamic load unbalance over the rotor increases DEL on shaft.

DEL on the tower FA significantly increased by aeroelastic interaction between tower frequency and 2P (2x rotational freq.)

➢ *Load mitigation: Compliant Tower Structure*



Amplification of DEL as tower freq. approaches the forcing one (2P).

To increase the frequency separation without modifying rot.speed -> more complaint tower structure.

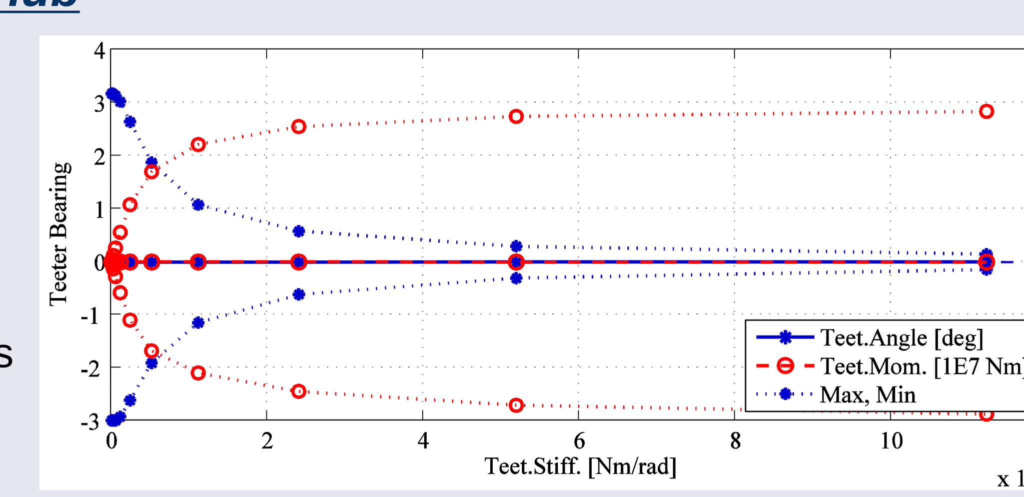
Softer tower -> control retuning toward slower response, might interfere with wave loads.

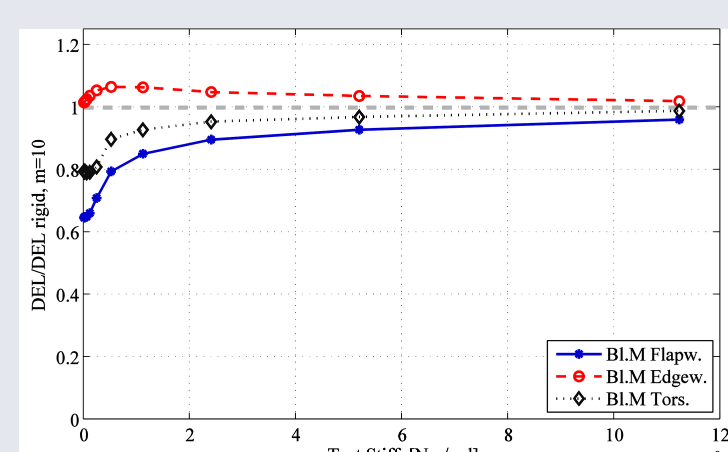
➢ *Load mitigation: Teetering Hub*

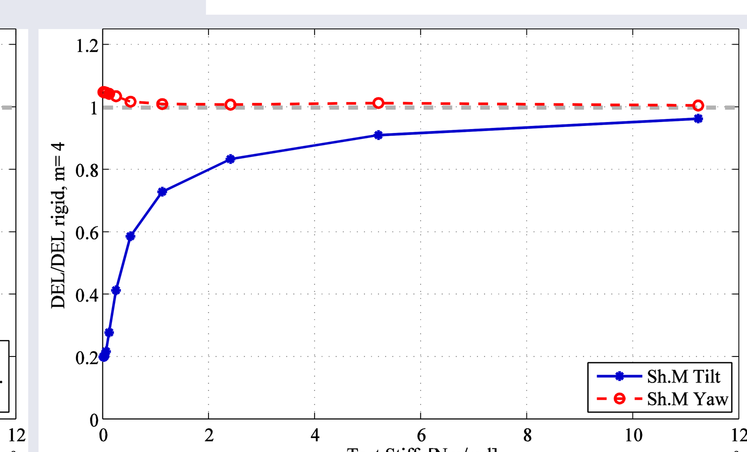
Loads from aerodynamic unbalance are alleviated by teetering hub configurations.

Low teetering joint stiffness -> low restoring moment, large teeter angle excursions.

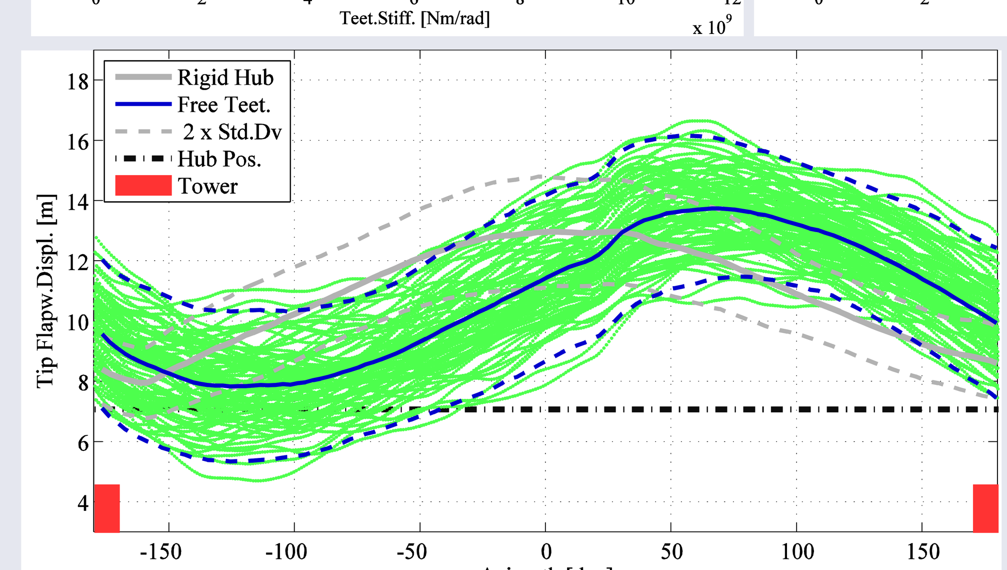
High stiffness -> small teeter angle excursions, large restoring moment variations and larger loads variation transmitted to the structure.







The teetering hub reduces the DEL on the shaft, and also on the blade root flapwise bending moment. The tower torsion DEL is also reduced



Low teeter stiffn. -> high load alleviation and high teeter angles -> high blade out-of-plane displacement.

In normal op.cond. maximum out-of-plane displacement occurs with horizontal blade (precession [5]) keeps blade-tower clearance.

In different op.cond. (startup, wake, high turb.) blade-tower clearance might be critically reduced.

Conclusions and future work

The proposed two bladed downwind rotor design reduces the rotor weight by approximately 30%, but has several drawbacks: 3 % reduction of the energy output due to increased tip losses, and increased DEL on blades, shaft, and tower.

A significant DEL increase in the tower can be avoided by separating the tower and the 2P frequencies; a softer tower structure would achieve so but might complicate the control tuning and interact with wave loads. A teetering hub configuration alleviates the loads on the shaft and on the blade but might reduce tower-blade clearance.

To conclude, the proposed constant solidity two-bladed rotor design has drawbacks unlikely to be compensated by the weight reduction.

Future work should consider alternative two-bladed rotor designs, with lower rotor solidity, and higher rotational speed. A lower solidity design would achieve lower weight savings, but also reduce the drawbacks observed with the current design.

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